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(54) APPARATUS FOR MEASURING THE THICKNESS OF ELECTRICALLY CONDUCTIVE THIN FILMS

(71) We, LEYBOLD-HERAEUS-VERWALTUNG G.m.b.H., (sole personally responsible partner of LEYBOLD-HERAEUS G.m.b.H. & Co. KOMMANDITGESELLSCHAFT), a German Company of Bonner Strasse 504, 5, Köln-Bayental, Federal Republic of Germany, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The invention relates to apparatus for measuring the thickness of electrically conductive thin films, without contacting the same.

Electrically conductive thin films, particularly films applied to an insulating backing or base, are required in various forms and for a wide variety of purposes in diverse technologies. For example, window glass for buildings and motor vehicles may be provided with a thin metal film to make them impermeable to infrared rays. In motor car windows such thin metal films are often also used as elements for heating the windows. On a large scale metal deposits on thermoplastic foil materials of very great length are used for the production of capacitors as well as for decorative purposes (optical effects). Paper tapes bearing vapour-deposiited metal coatings are used for instance as recording tapes in recording instruments for measuring purposes. In every case, particularly when the surface resistance of such a film is of importance, it is desirable to ensure that the thickness of the film is quite uniform and that its properties are reproducible in a large number of parts or in a very long length of a "continuous" product.

In practice a plurality of methods have been found useful for the production of such films, for instance vaporisation or atomisation (cathode atomisation) in vacuo, thermal decomposition of metal compounds as well as many electrolytically based processes. The rate of precipitation, i.e. the quantity of the electrically conductive film-forming material deposited per unit of time and surface usually depends upon a large number of factors which are often capable of being individually adjusted and controlled. Moreover, the time factor also plays a part because the resultant films may be thicker according to the length of time the method of application is continued. The controllability of these different methods is incidentally well known in the art.

However, the successful control of any such method presumes that the actual thickness of the film can be measured quickly, reliably without extraneous interference, and without the destruction of or damage to the measured material. Only the satisfaction of these requirements ensures that waste of time and money due to rejects will be avoided.

There has therefore been no lack of proposals to develop methods of measuring the thickness of films without making contact therewith. Photometric methods based on the measurement of the light reflected or transmitted by the film are limited to the examination of extremely thin films, i.e. of films thin enough to be optically transparent. A non-contact making method which is also applicable to optically opaque films and which is based on a measurement of the ohmic resistance of the film by capacitively coupling it with a measuring circuit has also already been proposed (German OFS No. 1,813,333). In this method the film which is to be measured together with its base is conducted over metal rolls, the base forming the dielectric of the capacitor constituted by the rolls and the metal film. However, this procedure calls for a considerable expense in apparatus for mounting of the rolls and in making sliding eletcrical contacts. Furthermore, the nature and thickness of the dielectric also affect the measured result and it is not always certain that the thickness of the dielectric is always constant. Furthermore, flutter of the measured material as it runs over the rolls varies the envelopment angle and this decisively affects the accuracy of the measurement. Finally changes in the contact resistance of

the sliding contacts may also cause faulty measurements.

Another proposal comprises inductively coupling the measured film with a measuring circuit for the purpose of determining its thickness (German Patent Specification No. 1,095,524 and German Patent Specification No. 1,098,718). The measuring instruments therein described are, however, designed with especial reference to specified measured objects, namely electrically conductive coatings in cathode ray tubes which are accessible from only one side. Since the thickness of the tube material considerably affects the measured result complicated compensating circuits had to be devised to eliminate these effects. Since the presence of an air gap would also adversely affect the measured results, known measuring instruments had to be placed on the measured objects so that a non-contact-making instrument, particularly one performed on objects in rapid motion, would be quite impossible. Another drawback of known measuring instruments is that the high frequency input currents are conducted to the evaluating apparatus through screened cables. Consequently the length of such cables is restricted to a few yards if the unavoidable capacitive loss is to be kept within bounds.

Finally, an inductive measuring apparatus has been proposed in the form of a measuring head operating on one side of a travelling film for determining its thickness (U.S. Patent Specification No. 2,438,506). Again the distance of the measuring head from the measured film is essential to the production of a reliable result. Therefore the measuring head is supported on a movable base which also carries the travelling film. The special element for locating the measuring head and the base is attached to the head and constitutes an undesirable additional component which it is frequently impossible to accommodate, particularly in vacuum equipment. Moreover, the thickness of the base in this method also enters into the measured result if it is desired to measure the thickness of an electrically conductive film. For measuring objects other than those in foil form this prior apparatus is not suitable.

When measuring the thickness of electrically conductive thin films, particularly in the form of coatings on electrically insulating backings or bases which move in relation to the measuring instrument or the measuring sensor, there is always a risk of the measured film changing its position in space in relation to the sensor and/or of the thickness of the base or backing varying which as such is unimportant, so far as the measurement is concerned. Moreover, it is desirable that the output quantity of the measurement should be capable of being transmitted to remote measuring or control equipment without the need for the provision of special devices to compensate different lengths of transmission line. Finally, changes in frequency of the alternating voltage required for an inductive measurement, particularly high frequency, is also desired to have as little effect on the result as is possible. The same requirement naturally also applies to temperaure variations which must not affect results.

It is therefore an object of the present invention to provide an improved measuring apparatus in which even significant changes in the position in space of the measured film in relation to the measuring sensor, or of the alternating frequency and the length of the electrical connecting cables and leads will have no detectable effect on the measured result.

According to the invention these objects are achieved by apparatus for measuring the thickness of an electrically conductive thin film, comprising two induction coils of identical size and design arranged to face one another across an air gap within which the film is to be located to measure the film thickness, a high frequency generator for energizing both coils co-directionally with a high-frequency current for producing eddy currents in the film, means for summing the voltage outputs of both coils and means for measuring the summation voltage for indicating the thickness of the thin film.

The proposed arrangement provides an arrangement which is completely symmetrical about the air gap through which the film is conducted for measurement of its thickness, and which in a preferred form deals with variations in the position of the film by compensating the same internally in the system by virtue of relationships which will be later explained in detail. The air gap and hence the admissible deviation can be considerably increased in relation to those admissible in conventional systems because non-linearities in the characteristic curves of the induction coils cancel each other out and compensate by the additive superimposition of the outputs. Frequency changes equally affect both induction coils so that within given limits the measured results cannot be adversely affected. Since the proposed arrangement lacks an oscillatory circuit formed with the aid of a capacitance in the feed line, changes in the length of connecting cables also have no undesirable effect on the results. Means for compensating capacity changes can therefore be completely omitted. Since the proposed apparatus also permits the provision of rectifiers and condensers in the direct vicinity of their incorporation in a unit assembly comprising the induction coils only direct currents are transmitted after rectification. Experience has shown that an

air gap of 7 to 10 mm width can be readily provided so that the risk of the travelling object bearing the film running into contact and the film being scratched is also largely avoided.

The invention is based on the principle of inducing eddy currents in a conductor in an alternating magnetic field. The strength of these currents depends upon the conductivity of the material and upon the density of the magnetic lines of force which pass through the conductor. The induced currents themselves generate a field which opposes and weakens the primary field. The result is a damping effect on inductivity causing the primary field, and this is due to eddy current loss in the conductor. The inductivity of the measuring coil decreases correspondingly. When such a coil is fed with high frequency alternating current the introduction of an electrical conductor into the magnetic field will therefore result in a decrease of the voltage across the ends of the coil. The closer the measured object is to the the coil the greater will be this damping effect. However, in the proposed symmetrical disposition of a pair of coils a closer approach of the conductor towards one coil involves an increase in its distance from the other coil and a corresponding reduction in the damping effect on that side. In the proposed combination of the induction coils the change in voltage across the two coils is therefore independent of the position in space of the measured object. The voltage drop across each induction coil can be plotted in the form of a "characteristic" curve which is substantially linear beyond a given distance from the induction coil. By superimposing the two characteristic curves a fresh curve representing the sum of the two voltage drops is therefore obtained which within a region of adequate width between the two coils is substantially constant. These relationships will be later further explained in the context of the particular description.

The effectiveness of the induction coils can be further improved if, the coils are embedded in ferrite shell cores having open sides which mirror symmetrically face each other across the air gap. Moreover, the effect of the non-linearity of the relationship between damping effect and the distance of the film when the latter is in direct proximity with the coils can be eliminated if insulating plates are provided on both sides of the air gap and these plates are thick enough to prevent the film that is to be measured from entering the region where the response of the induction coils is no longer proportional to the distance.

Moreover, in order to eliminate the effect of temperature variations on the precision of the measurement it is preferred to provide a pair of reference coils which are identical in design and size to the measuring induction coils and are arranged to face each other at the same distance apart as the measuring induction coils, and to connect them with reversed polarity to the measuring coils for the purpose of providing electrical compensation. A direct current, which is desirable for the purpose of evaluating the signals from the several induction coils, can easily be produced by including in the output lines of all the induction coils separate rectifiers and smoothing condensers and then combining the several outputs. If the polarity of the rectifiers is appropriately chosen the desired additive and subtractive effects in the combination of the signals are easily obtained.

In a useful arrangement the high frequency generator, rectifiers, smoothing condensers and summation resistors together with the induction coils may be combined in a single assembly unit in which the remaining spaces are preferably filled with a casting resin. Such a unit needs very little space and can be readily accommodated in the interior of a self-contained installation, such as vacuum vaporising or cathode atomising equipment. The unit may be enclosed in a U-shaped housing in which the induction coils are located in the sides of the "U" facing each other across the air gap provided by the mouth of the "U". In this way the assembly forms a measuring head which can be located in the apparatus in which the film that is to be measured is produced so that the U-shaped housing embraces the measured object. The output signal need then merely be taken to an indicating instrument and/or to a controller controlling the desired parameters of the production process of the measured film, use being made of a multiple pin and socket connector.

An embodiment of an apparatus according to the invention and the manner in which it functions will now be more particularly described with reference to the accompanying generally schematic drawings in which:—

Figure 1 shows the general arrangement of the apparatus, and

Figure 2 is a graph showing the voltage drops in the induction coils as a function of the position of the measured object.

With reference to Figure 1 there is provided a generator 10 supplying a high frequency alternating voltage which is provided with power through input terminals 11. The generated alternating voltage is applied to four input resistors 13*a* to 13*d*. From each of these input resistors a conductor 14*a* to 14*d* leads to an associated induction coil 15*a* to 15*d*. The induction coils are identical in size and design and are embedded in appropriate ferrite shell cores 16, the open sides of the ferrite cores of coils 15*a* and 15*b* facing each other across an air gap 17 in mirror symmetric fashion. An object 18 in the form

of a synthetic plastics foil 19 carrying an electrically conducting aluminium foil 20 which has been vapour deposited in a vacuum is positioned in the air gap 17 for measurement of the thickness of film 20. Between the induction coils 15a and 15b on each side of the air gap 17 insulating plates 21 are provided. These plates are sufficiently thick to prevent the film 20 that is to be measured from entering the zone where the measuring sensitivity of the induction coils 15a and 15b is non-linear. The remaining air gap 17 between these two insulating plates 21 is still wide enough to avoid contact of the object 18 with the sides of the air gap even in the event of flutter.

The induction coils 15a and 15b provide a signal which depends upon the conductivity, namely the thickness, of the film 20 and a compensating voltage is obtained from the induction coils 15c and 15d which corresponds to that of the induction coils 15a and 15b if the objects 18 were absent. For the purpose of maintaining electrical symmetry an insulating plug 22 is interposed between the induction coils 15c and 15d. Plug 22 functions to maintain the same distance between the induction coils 15c and 15d as that between the induction coils 15a and 15b. The coils 15c and 15d, hereinafter termed compensating coils provides for temperature compensation of the entire arrangement as well as for the compensation of any possible frequency drift.

Any electrically conductive object introduced into the air gap 17 causes a voltage deviation from 0 to a negative voltage. The direction of the current through the induction coils 15a and 15b (as well as through compensating coils 15c and 15d) is the same, so that movement of the object away from the induction coil 15a will cause the effect in induction coil 15a to decrease, whereas at the same time a stronger signal appears across the induction coil 15b. This result is illustrated in Figure 2. Movement of the object 18 from left to right causes a change in the voltage u_1 obtainable from induction coil 15a, this change being in the direction indicated by the curve. The same applies to the voltage u_2 in induction coil 15b. The sum of the two voltages u_1+u_2 is plotted above the two curves u_1 and u_2. It will be seen that the summation curve is substantially horizontal within the region between the two vertical chain lines. In other words, changes in position of the measured object 18 within this region are practically without effect on the result of the measurement. The region where linearity ceases, reflected in the summation curve by its descending ends, is cut out by the provision of the insulating plates 21 on the induction coils 15a and 15b, the plates preventing the object 18 from entering these regions. The linear part of the summation curve u_1+u_2 is still wide enough to make adequate allowance for positional deviations of the object 18.

The voltages obtained from the several induction coils are applied by appropriate leads to four rectifiers 23a to 23d. The presence of associated smoothing condensers 24a to 24d satisfactorily eliminates ripples in the signal voltages so that only direct currents flow through the relative summation resistors 25a to 25d and no further attenuations will take place.

The signal voltages are taken via the summation resistors 25a to 25d through leads 26 and 27, with due regard to the polarities of the rectifiers 23a to 23d, to an operational amplifier 28 the output of which is taken through a lead 29 to a measuring and indicating instrument 30. Naturally this instrument could be replaced by automatic control means for controlling the operating parameters in the production process of the film 20 on the object 18. In the absence of an object 18 in the air gap 17 the instrument 30 indicates "0". An object introduced into the air gap will cause a corresponding voltage deviation. The instrument 30 can be calibrated by reference to objects 18 bearing films of defined thickness or of defined surface resistance so that direct readings can be taken. Since direct currents flow through the lines 26 and 27 the length of these lines is not restricted in any way.

The overall arrangement in Figure 1, with the exception of the measuring and indicating instrument 30 itself, can be combined in an assembly unit contained in a U-shaped housing 31 in which the induction coils 15a and 15b are located in the sides 32 and 33 of the "U" facing the air gap 17. The housing is very schematically indicated by a hatched line. The housing 31 is preferably filled with a castable insulating composition, such as a castable synthetic resin. The assembly unit thus forms a measuring head which is connectable by a multiple pin and socket connector to electrical input and output lines. These connectors would combine for instance the terminals 11 and the connections 26 and 27.

WHAT WE CLAIM IS:—

1. Apparatus for measuring the thickness of an electrically conductive thin film, comprising two induction coils of identical size and design arranged to face one another across an air gap within which the film is to be located to measure the film thickness, a high frequency generator for energizing both coils co-directionally with a high-frequency current for producing eddy currents in the film, means for summing the voltage outputs of both coils and means for measuring the summation voltage for indicating the thickness of the thin film.

2. Apparatus according to Claim 1, wherein the induction coils are embedded in ferrite shell cores having open sides which face each other across the air gap.

3. Apparatus according to Claim 1 or Claim 2, wherein insulating plates are provided on both sides of the air gap, the thickness of the plates being so calculated that the film is prevented from entering the region where the measuring sensitivity of the induction coils rises non-linearly.

4. Apparatus according to any one of Claims 1 to 3, further comprising a pair of compensating induction coils which are identical in design and size to the measuring induction coils and are arranged to face each other at the same distance apart as the measuring induction coils, the output of said compensating coils being connected in reverse to the output of the measuring induction coils for the purpose of providing electrical compensation.

5. Apparatus according to any one of Claims 1 to 4, further comprising rectifiers and smoothing condensers for separately rectifying and smoothing the outputs of all the induction coils prior to summation of the outputs.

6. Apparatus according to Claim 5, wherein the high frequency generator, the rectifiers, the smoothing condensers, the summation means comprising resistors, and the induction coils are combined in one assembly unit.

7. Apparatus according to Claim 6, wherein the assembly unit comprises a U-shaped housing the mouth of which constitutes the air gap, and the measuring induction coils are located in the sides of the "U" facing each other across the air gap.

8. Apparatus for measuring the thickness of an electrically conductive film substantially as hereinbefore described with reference to the accompanying drawings.

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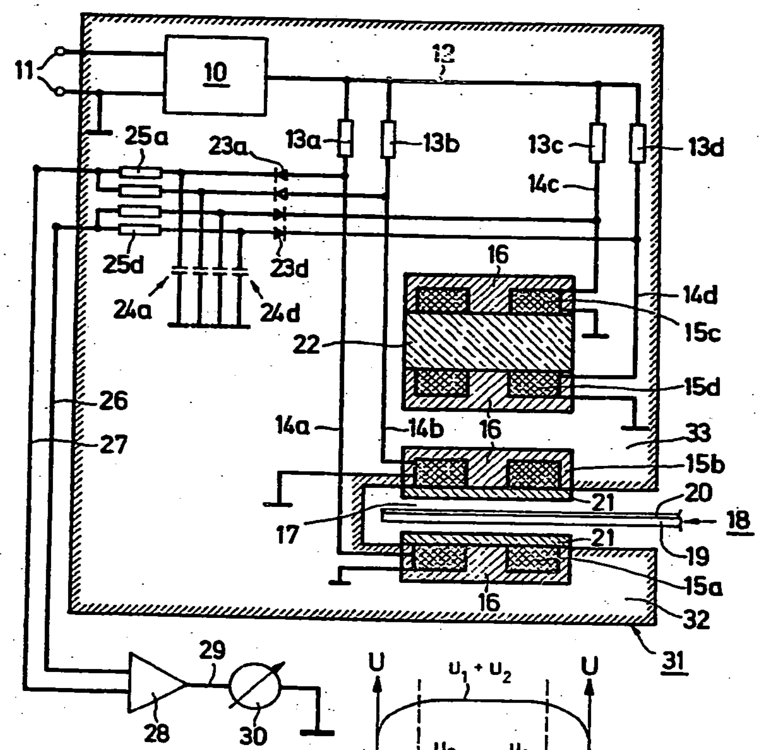
1452417 COMPLETE SPECIFICATION

1 SHEET *This drawing is a reproduction of the Original on a reduced scale*

FIG. 1



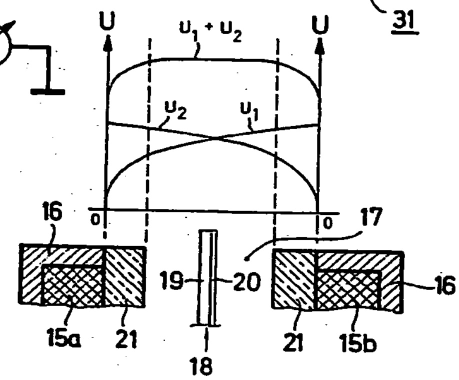


FIG. 2